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Landfill Waste from the Production of Nickel and Cobalt in the Slovak Republic

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Abstract

The complex of the former Nickel smelter is located in the Podunajská rovina (Danubian plane) on the border Sereď town and village Dolná Streda. The landfill presents a highly negative hazardous element for environment and quality of life. It is a very anthropogenic damaged area which is located in the agrarian landscape. Some parts of the areas of the agricultural soils were from the fund of the agricultural soils excluded. Degradation of the region is the result of the non-conceptual socialist industrialization of Slovakia. After 30 years was stopped the production of nickel and cobalt (1963-1993) for economic and ecological reasons. Waste from production of nickel and cobalt remained here and degrades the environment in nowadays. Today is the landfill of waste a private property and owner exports the waste to foreign countries.

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Introduction

The main reason construction of the Nickel Smelter in Slovak Republic was embargo of capitalist countries to export of nickel into socialist countries. The construction of the smelter started in 1959 and first nickel was produced in 1963. The main raw material was the lateritic iron-nickel ore which was imported from Albania (content of nickel 1 %/1 tonne ore). Poor quality of ore was the consequence of creation massive amounts of waste (during 30 years 9 mil. tons). In 1993/94 production of Nickel Smelter been stopped but the waste (lúženec) remained and damages the structure of landscape and environment 23 years after end of production and before it was 30 years.

Material and Methods

Methodology is oriented towards the research of the current landscape structure of the observed territory on the basis of the analysis of its individual components. The current structure of the landscape on landfill of lúženec according to the corresponding categories of landscape elements and new individual elements were identified by using the interpretation of colourful satellite orthophoto map from 2012 (Fig. 1) with high resolution. Digitalization of spatial data of individual elements were processed manually by method „on screen" by software ArcView GIS 3.1 in scale 1: 3 000. Identified landscape elements were consequently included into a specifically modified legend according to their content characteristics. Obtained results were verified in the field research realized in 2013.

Study area

The landfill of lúženec was located without any isolation on floodplain of Váh (river) which consists of the lithological variable (sandy-clay and clay) Holocene sediments (10 - 12 meters thickness) which are stored on the Neogene sediments (1). The permeability of lúženec is very high so rainfall will pass quickly through the landfill mass. Big part of them is evaporated, because the lúženec absorbs solar radiation very intensively. Landfill is 45 m high, 800 m long and 550 m wide (acreage is about 35 ha). It lies at an altitude of 125 m in Podunajská rovina (Danubian plane) at Sereď town.

Composition of lúženec and the possibility of its utilization in the industry

The landfill of lúženec was created as fusion of the several tailing ponds of the waste. Lúženec is a waste from the colour metallurgy of Nickel and Cobalt based on the Caron hydrometallurgical process. From petrographical composition lúženec (mud from production of nickel) is homogeneous a mo-sand material of black colour and originated by milling and laundering the Albanian lateritic iron-nickel ore (at present the volume of the dump is 6.5 million [t]). Lúženec is medium rich Fe - concentrate and from this aspect could be used for smelting in blast furnaces (2) in black metallurgy, but locker patch into the blast furnace is only 50 kg (not more because it contains chromium). The use of lúženec in the industry of building materials as additives for the cement was stopped in terms of content chromium. This element is under EU law inadmissible in construction materials is harmful to health. Small part of lúženec is used in the washing of brown coal. The above use of waste mud from nickel is possible and is substantiated by research, but given the fact that the owner of landfill is a private company its activities dealing with waste mud from nickel except that the material is today mined are not known.

Table 1 show that the Nickel Smelter produced 3000 tons of nickel per year and 60 tons of cobalt and 300,000 tonnes of waste. For 30 years at full operation smelter produced about 90 000 tonnes of nickel + 1 800 t of cobalt and 9,000,000 million tonnes waste. Production of metals represents 1.02% from waste. Lúženec by chemical composition contains the most iron around 50-80%. Represents Fe - concentrate with a higher content of chromium and aluminium. Annual consumption of chemicals was 5624 t and for 30 years it was 168 720 t (acids, ammonia and sodium sulphide). It is very

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difficult to imagine that all these substances were part of waste mud from nickel production and were stored on landfill and penetrated into the groundwater flood-plain the Váh (river).

According the chemical analysis of soil on the waste mud from nickel in Table 2 we see that the soils there are strong alkaline pH of 8.5. Organic content (TOC) is very very low 0.05% and C: N ratio is 0.74: 00:05. Total content of Fe_2O_3 is 78% and Al2O3 3.27%. The highest is content of chromium 24 300 mg / kg and nickel 2 920 mg / kg. Content of zinc is 300 mg / kg and copper content is 49 mg / kg. The soils (Spolic Technosol) on waste mud from nickel production have unfavourable characteristics are toxic and do not create conditions for the formation the vegetation cover which was reflected in attempts to reclamation of landfill.

Figure: 1 Satellite image of study area (© Landsat, 2012).

Measurand	Unit	A horizon	Method
Depth [m]		0.2	
pH (H_2O)		8.50	E
TOC	[%]	0.05	HTO
C	[%]	0.74	EA
N	[%]	0.05	EA
Fe2O3 Total content	[%]	78	RFS
Al2O3	[%]	3.27	RFS
Ni	[mg/kg]	2 920	RFS
Cr	[mg/kg]	24 300	RFS
Cu	[mg/kg]	49.0	RFS
Zn	[mg/kg]	300.0	RFS
Faction ≤ 0.01	[%]	11.1	AS

Table 2: Chemical analysis of lúženec in year 2012.

Source: ŠGÚŠ, Geoanalytical laboratories, ASL STN EN ISO/IEC, Spišská Nová Ves.
Slovak Republic

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Characteristics of the present landscape structure on the landfill of lúženec

Landfill waste mud from nickel is composed from anthropogenic technogenic sediment. It is industrial waste intensive black colour. The landfill is conspicuous anthropogenic landform which contrasts sharply with the surrounding relief flatland of Podunajská rovina (Danubian Plain). According the classification of anthropogenic relief forms [3-7] include the landfill waste on the basis of respecting all criterions of the classification into the meso-form of anthropogenic relief. The form of landfill is the accumulating tableland and is not inflammable and has convex form in the stage of maturity until old age with homogeneous composition (Figure 1).

Annual production of metal in [t], [%] from waste	Annual production of waste and for 30 years in [t],	Chemical composition of lúženec in [%]	Annual consumption of chemicals in [t]
3000 Ni, 60 Co, 1,02 % from waste	300 000 lúženca, 9 000 000 .lúženca	50 - 80 Fe, 2,5 – 3,5 Cr_2O_3, 6 – 8 SiO2, 6 – 8 Al_2O_3, 2,5 – 3,5 CaO, 0,17 % Ni, 0,6 – 0,18 P_2O_3	2 800 NH_4OH, 1200 Na_2S, 611 HCl, 1 013 H_2SO_4

Table 1: Production of metal, waste and chemical composition of lúženec, annual consumption of chemicals in Nickel smelter in Sereď (1963 – 1993)

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Within the landfill proceed now these geomorphological processes: gravitational geomorphological processes (creep, splash sheet-wash) geomorphological processes of sheet erosion and linear erosion (rain-pluvial drip erosion, sheet drainage erosion, linear drainage erosion which is divided into drainage rill and drainage gully erosion), geomorphological processes wind erosion (wind deflation, whirlwind deflation, wind-carving), geomorphological processes of direct anthropogenic erosion (that includes the mining and adaptation the body of landfill for the mining) which accelerates all previous geomorphological processes on landfill.

Landfill is located in the warm climate region [8] in the climate subregion T1, which is warm, very dry with mild winter. Average January temperature is -3°C. It is a territory with the deficit of precipitation 100-150 mm per year. The average annual air temperature is here 9.5°C and the average July temperature is 19°C. It is characterized by a high number hours of sunshine per year over 2000. The prevailing wind flow during the south-east and north-west wind (50.2%). The area is well ventilated and there is dispersion of air pollutants in the ground layer of the atmosphere.

The territory belongs to the river basin of Vah. Landfill lies between the river Váh (1 700 m from river) and of the watercourse Derňa. Ground waters are reacted to the water regime of Vah. Their collectors are located at a depth of 2 to 3.5 m below the surface and forms by the infiltration from waters of Váh (river) and partly from seepage of precipitation.

On the landfill waste and the site of the former Nickel Smelter are technosols (Spolic Technosols, the soils on anthropogenic substrate technogenic origin). Soils on the technogenic substrates are toxic [9].

Fauna of the area belongs to the Pannonian basin province, in the sub-province of their West Pannonian basin very strong steppe and forest steppe nature, but most species was agrarian and industrial operations decimated. It is a territory with a clear above-average used to distort the natural structure and belongs to unstable regions with low environmental quality. Detailed analysis of the land cover has not yet been made for this area. Understanding of current state of the structure of the landfill has a significant impact on quality of life in the region at present time and we consider that it is very important. According to Ružicka [10] we have identified nearly 189 landscape elements (patches), which are included by specific character of the region into 3 groups and 6 subgroups (Table 3).

The land cover of the landfill represents completely a new type and the representation of plant species is a unique. It is not similar to habitats in the others landfills. From the aspect of representation of individual groups most landscape elements are of herbal-grass areas (Banásová, Hajdúk, 1984).

Group	Subgroup	Area in ha	%	Number of patches
Forest and non-forest vegetation elements	Populus canascens with Calamagrostis epigejos area	2.5	9.0	117
Herbaceus elements	Calamagrostis epigejos area	3.8	14.0	21
	Artemisia absinthum area	3.7	13.0	1
	Phragmites communis area	0.2	0.4	1
	Other areas	6.8	23.6	17
Uncovered substrate Elements	Uncovered area	11.0	40.0	32
Total		28	100	189

Table 3: Landscape elements area and number of patches in 2012.

Source: Field research in years 2012/ 2013

Largest number of the plant species is in foot of dump to a height of about 2 two meters. In these parts is lúženec deposited on the imported material (gravel) which formed the basis for the establishment of landfill in past. Increased transport of seeds from neighbouring fields and specific microclimate of this contact zone is a key to the existence of dense vegetation on the foot of the slopes of landfill (11). Vegetation cover has in this area abundance approximately from 60 to 80%. In the first zone at the foot of the dump are plants with deep roots, for example: *Cardaria draba, Carduus acanthoides* and *Convolvulus arvensis*. Above it there are other ruderal species as *Agropyrum repens, Reseda lutea and Artemisia absinthum*. From other species is here *Bromus inermis, Cynodon dactylon and Arrhenatherum elatius*.

In the higher part on the slopes of landfill on the pure lúženec vegetation is a sporadic and is concentrated of bunches and occupies the smaller depressions in the oldest parts of the landfill. The vegetation of the landfill is here mostly incoherent and from the aspect of composition of the species homogeneous. Grasses Dactylis glomerata, Poa pratensis (rare species) and Festuca rubra are found as remnants after the failed hydroseeding process (1976-1978 and 1980). The last two designated species are on lúženec sporadically. The most vital species with high seed germination capacity (78%) is Dactylis glomerata as confirmed by experiments realized in the past [13].

From the plant species of spontaneous succession are on the lúženec most frequently *Centaurea stoebe, Carduus acanthoides* and *Salsola kali* [12]. The trees is represented mainly Populus canenscens, which created discontinuous areas on the flat surface of landfill in the central and southern parts. Its undergrowth consists of *Calamagrostis epigejos. Calamagrostis epigejos* creates the large areas also on the east, where the top plateau of the dump decreases. In the southeastern part of the landfill are monocenosis with *Artemisia absinthum*. Near the eastern edge of the landfill is found a smaller shallow terrain depression filled with water with the associations of *Phragmites communis*. Uncovered areas of occupy more than 11 ha, 40% of its total area (Figure 2).

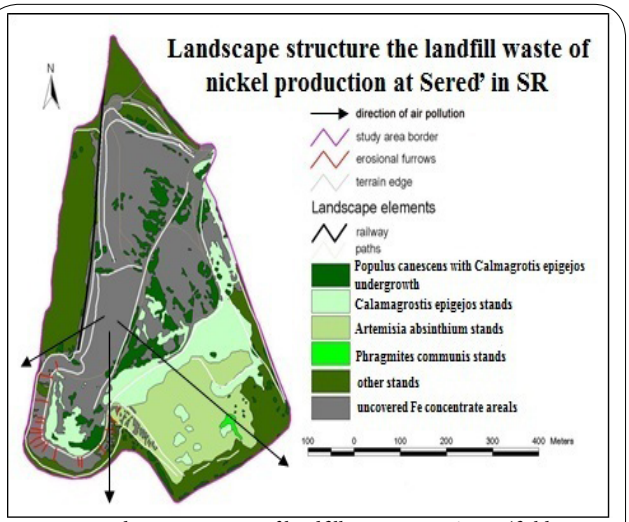

Figure 2: Landscape structure of landfill in year 2012/2013 (field research).

The impact the dump of lúženec on the environment

Environmental contamination in Sereď lasted 30 years during full operation of the Nickel smelter and not ended after liquidation the smelter in the years 1993/94 because the sources of pollution remained here (landfill of lúženec) and pollution persists.

The lúženec from the beginning of storage in 1963 until the present is a source of emissions the polymetallic dust from the uncovered area of the landfill (deflation). Deposition of polymetallic dust on soils, water and vegetation cover and on built-up areas is the final process of the wind erosion. This is in present time a serious problem of quality environment and is related to human health. Here is a high prevalence of respiratory diseases and diseases of unknown aetiology, allergies, as well the formation of neoplasm not just in adults, but increasingly also in a paediatric population. In territory is not station for monitoring of air pollution.

Monitoring of groundwater around the landfill of lúženec was conducted 1990 - 1993 (after 27 years of operation Nickel smelter, data are not published). The analysis of samples demonstrated the extremely poor quality of groundwater (high concentrations of sulphates, ammonium, and nitrates). Was exceeded the limit of state standards [14]. Pollution of ground and surface water was left on its natural elimination.

The content of nickel in agricultural soils is 7-8 times higher than its value of the natural background in other locations [15]. It is estimated that the area of agricultural soils that is affected by the emission influence of pollutants from the production of nickel are of 1500 ha. To this situation is significantly contributes deflation of lúženec from the dump. The secondary is soil cover affected by irrigation (cumulative effect - deposition of hazardous elements in soils by contaminated water). The initially climatic and soils conditions of the region should prerequisites for the development of the modern trends to of ecological agriculture. Contamination of soils and the total devastation of the territory should be excluded these trends.

The projects processed since 1994 for elimination the impact of landfill on environment

The first project: mining of lúženec as material for the production of pig iron and Ferro-alloys. Experimental metallurgical research has demonstrated that this form of using is not possible from the aspect of composition lúženec.

The second: the use of lúženec as an admixture in cement - prohibited by EU legislation for the content of chromium (health hazard element).

The third: the use of lúženec to the washing of brown coal - this form is of insignificant in relation to its quantity.

The fourth: the redevelopment of the dump to the greening - for that possibility was realized experimental research which designated the ability of the selected plant species to grow on the toxic waste. The research results showed that reclamation to the greening is possible, but only with the 10% admixture of sludge from sugar beet from the production of sugar into lúženec for improving properties of lúženec [13]. The reclamation was performed on 8 ha of the dump.

The fifth: the protection against the spread of polymetallical dust into the air - consisted of sprinkling the landfill with water - is ineffective as the equipment for this process is inoperable.

The sixth: The elimination of groundwater pollution through the construction of the hydraulic membrane and the amelioration channels has not been implemented due to high costs to investing and operating. Elimination the impact landfill on groundwater was not done as well as the planned groundwater monitoring for a period 50 years. All possibilities the remediation impact the landfill on the environment have been processed only into the projects only reclamation by seeding presented in fourth project.

Conclusion

In this paper we focused on the current landscape structure on the landfill lúženec and its impact on the environment. Physical and chemical properties lúženec were the cause creating of a very specific ecosystem that does not have equivalent in the natural landscape. The liquidation the lúženec landfill by the mining is an ineffective. Large amount waste excludes use the method phytosanation. Method of microwave vitrification the lúženec is very costly [16], but probably the most effective. The essence of vitrification procedure is transformation the lúženec on the vitrite, which has a high chemical stability and water resistance. The method can be used on the large masses especially industrial wastes and it is important from aspect of waste reduction. It is a very perspective method. Remediation of the landfill is not currently possible, because it is private property.

Competing Interests

The authors declare that they have no competing interests.

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